

Review of Computational Optimisation Techniques for the Coordination of Over-Current Relay Protection in Sub-Transmission Stations

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Abstract: Adding more power plants and transmission stations to the power system of Nigeria has been influenced by a substantial and rapidly growing nonlinear load demand over the past decades. This has resulted in an exponential increase in fault current due to complexity inherent in the Nigerian power system network. If not properly coordinated, this can lead to undesired tripping of the protection relays. Hence, it is crucial to ensure that relays installed in the grid can effectively detect and isolate fault current from both the upstream and downstream in order to maintain the integrity of the grid. To achieve this, an optimal Predictive, Analytical and Coordination Scheme (PACS) for over-current relays (OCRs) is introduced into the system. This paper provides a comprehensive examination of various optimisation techniques used for achieving PACS in the integrated power networks with review of literature on OCrs. The review emphasises the features, benefits and drawbacks of the techniques employed to address over-current protection coordination issues in a balanced and objective way. Additionally, the paper discusses potential avenues for future research in the field of PACS that could lead to significant advances in the field of optimal OCR coordination.

Keywords: Electricity transmission; Optimisation techniques; Over-current faults; Protective relays; Relays coordination.

1. INTRODUCTION

The occurrence of faults in the electrical power system network poses serious risk of system failure and revenue loss, particularly noted for long lines and remote locations. The need for proper functioning of the network by preventing electricity supply disruptions and safeguarding valuable electrical facilities from being destroyed requires putting in place reliable protection. To achieve optimal protection of electricity networks requires effectively coordinating the protection relays. This aims at promptly identifying and isolating faulty areas within safety margins, to avoid unnecessary time delays [1-4].

A variety of protection schemes are employed, particularly at transmission substations, to ensure the safety and reliable operation of the electrical power system, by detecting and isolating faults or abnormal conditions within the substation and the associated transmission lines [5]. Some of the protection schemes are over-current, distance, differential, transformer, busbar and breaker failure protection relays [6]. These relays detect faults by monitoring electrical quantities, namely voltage, current, impedance and frequency, and comparing them to predefined thresholds, with the specific method employed depending on the type of fault being targeted and the protection scheme being utilised [7]. The protective relay used in electricity transmission stations can be categorised into over-current, distance, pilot, differential and directional relays.

Relay coordination in a substation is the process of setting and configuring protection relays in a coordinated manner to ensure efficient and selective operation during faults or abnormal conditions. The primary goal is to achieve proper discrimination, where only the relays closest to the faulty section operate to isolate the fault while minimising unnecessary tripping of unaffected portions of the system [8, 9]. Factors that determine the frequency of relay coordination in a transmission substation depend on the complexity of the substation, system changes, operational requirements, and industry standards [10-12]. Importantly, relay coordination is performed during the initial commissioning of the transmission substation or whenever there are significant changes in the protection scheme [13, 14]. Secondly, regular review and updating of relay coordination is important to account for any changes in the substation or power system [15]. This includes modification of the substation layout, addition of new equipment, changes in protection zones, or alterations in network configuration [16, 17]. Frequent faults, system disturbances or coordination issues in a transmission substation require fault analysis and coordination. A study was conducted to review existing protection schemes and address specific problems that were identified [18, 19].

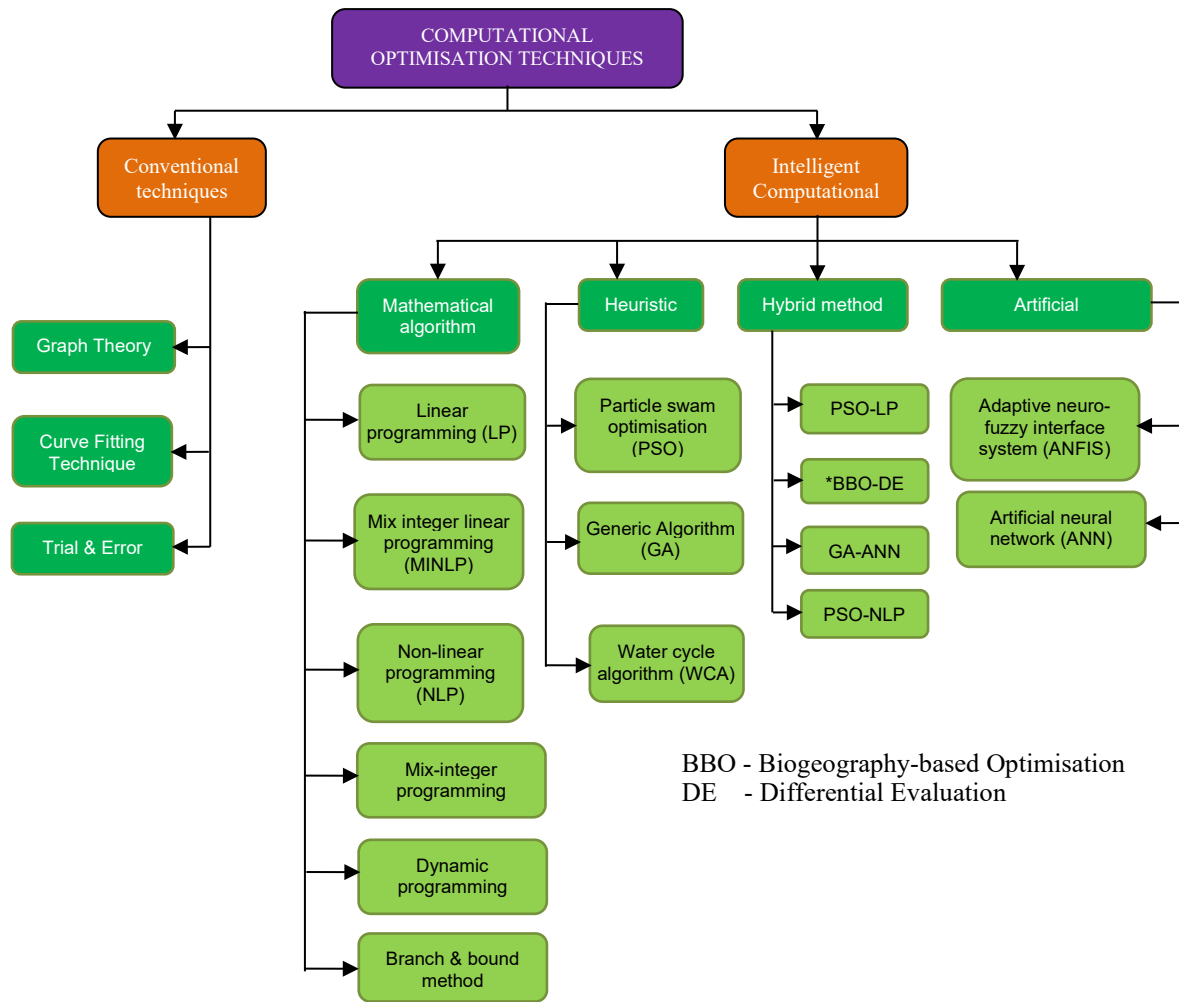


Figure 1. Different optimisation techniques.

This paper provides an objective, pragmatic and comprehensive examination of various optimisation techniques that could be deployed to achieve optimal Predictive, Analytical and Coordination Scheme (PACS) for over-current relays (OCRs) in integrated power networks by emphasising the features, benefits and drawbacks of the techniques. In addition, the paper discusses potential avenues for future research in the field of PACS that could lead to significant advances in the field of optimal OCR coordination.

2. COORDINATION OF OVER-CURRENT RELAYS

Coordination of OCRs is achieved with dynamic protection devices, which present a challenging optimisation problem in integrated networks, and serve as main protection for both sub-transmission or distribution networks and backup protection for transmission lines [20-23]. Achieving optimal OCR coordination involves determining the appropriate time multiplier setting (TMS) and plug setting current for the relays, while ensuring proper coordination between primary and backup relays and minimising overall operating time [24]. Over the years, researchers have explored various computational approaches to tackle the OCR coordination problem. These approaches can be categorised into five main types, namely [25, 26]:

- a) Conventional methods
- b) Nature-inspired algorithms (NIA)-heuristic approaches
- c) Mathematical techniques
- d) Hybrid techniques
- e) Artificial intelligence (AI)

By utilising the techniques in Figure 1, which is the classification of optimal OCR coordination and different optimisation techniques, the aim is to improve OCR performance, enhance fault detection and isolation capabilities, and optimise relay settings for efficient network protection [27, 28]. Continued research and development in OCR coordination techniques are crucial to address emerging challenges in modern power systems and ensure reliable and effective protection in integrated networks [29]. Summary of the major features, advantages and limitations of the approaches listed above in association with the optimal OCR coordination optimisation techniques are stated in Table 1.

Table 1. Major features, merits and limitations of OCR coordination approaches.

Categories	Techniques	Key Features	Benefits	Drawbacks
Conventional [48,49,50]	Trial and Error	The transparent plate has been shaped to match the relay's current-time characteristics.	Appropriate for simple power networks	This approach is not suitable for large networks because it is time-consuming, has a slow rate of convergence, and results in relatively high time dial setting (TDS) values for the relays.
	Curve- fitting	Time-inverse operating curves are generated for different types of linear and nonlinear relay time-current characteristics.	Method available only at the period of time.	Inaccurate results will lead to suboptimal outcomes and setting violations
	Graph Theory	Break points relay is recognized.	Optimal solution achieved rapidly through convergence	The careful choice of a breakpoint is of utmost importance.
NIA Heuristic [19,22,51,52, 53]	Evolutionary Programming (EP)	Enhance the configuration of the relay to prevent getting stuck in local optima	The handling of constraints is proficient	Mis-coordination may arise, leading to extended computational duration.
	Genetic Algorithm (GA)	Enhancing the objective function through the incorporation of additional terms to address mis-coordination	Proves highly efficient, adaptable, and precise	Extended computational time
	Continuous Genetic Algorithm (CGA)	Minimize the time of relay operation through the implementation of a CGA	Ensuring that all constraints are met to a satisfactory extent	Satisfaction not completely fulfilled
	Continuous Particle Swarm Optimisation (CPSO)	Minimize the time of relay operation through the use of a continuous genetic algorithm while ensuring that all constraints are met to a satisfactory extent, although not completely fulfilled	The individual within the CPSO population becomes more discerning in locating the optimal solution.	The iterative process leads to increased time consumption for each sub-problem stage.
Hybrid [52,54,55,56, 57]	Modified Particle Swarm Optimiser (MPSO)	Enhance the coordination of OCRs through the utilization of PSO	Offers ease of implementation and robustness	It experiences partial optimisation issues within the system.
	Immune Algorithm and Particle Swarm Optimisation (IA-PSO)	Utilised through the combination of the immune information processing mechanism and PSO.	Achieves the swiftest convergence rate, leading to the attainment of minimal Coordination time interval CTI values.	Does not address more intricate scenarios, which encompass conflicting objective functions and diverse system topologies.
	GA-PSO	Expedite the process of optimisation while reducing the need for manual tuning steps.	Exhibiting high dependability level in coordination, capable of identifying pairs where backup relays fail to respond to faults.	No outcomes are presented, neither is any validation conducted for the cases tested under network reconfiguration.
	Nelder-Mead and Particle Swarm Optimisation (NM-PSO)	Enhance the efficiency of relay setting optimisation through the utilization of PSO and the implementation of the	Results in rapid and improved convergence rates	This approach does not take into account continuous values

		Nelder-Mead (NM) method		
	PSO-DE	Employ a pair of distinct evolutionary algorithms to initially explore the search space on a global scale and subsequently on a local scale	This approach enables the discovery of superior TDS and plug setting (PS), thereby minimizing the operating time of the relays and reducing the (CTL.)	It lacks robustness
	Simulated Annealing-based Symbiotic Organism Search (SASOS)	Introducing a novel objective function by integrating addition of operating time for both far-end and near-end OCR relays to achieve fault clearance	The algorithm necessitates minimal function evaluations to reach the optimum	Suitable for smaller bus systems, although it demands comprehensive statistical analysis and parameter tuning to further enhance the efficiency of SASOS.
Mathematical [58,59,60,61, 62]	MINLP-solver	A 2-stage analytical method employed to eliminate infeasibility in the MINLP coordination problem and reach an optimal solution within a few iterations	Further analysis and parameter tuning have the potential to enhance the efficiency of SASOS and bring to light its effectiveness.	This iterative process results in increased time consumption for each sub-problem stage
	Analytic approach	A novel iterative numerical solution for optimizing relay settings	Which exhibits rapid convergence, minimal run time, initial values independence, and insensitivity to coordination order	It lacks a formulated mathematical approach to guarantee the convergence of the introduced algorithm
	Interval linear programming	Transform the inequality constraints for each relay pair into interval constraints, representing uncertainty in topology within the context of the extensive coordination problem	There is reduction in the quantity of coordination constraints substantially	The validity of the outcome remains unconfirmed
	Mathematical Programming Language (MPL)	Employing an interior point optimisation (IPOPT) solver based on the MPL	Yielding favourable outcomes within a reasonably short timeframe, rendering it well-suited for the adaptive protection scheme	There is an absence of a comparative analysis to substantiate the method's efficiency.
	LP-interior point algorithm	Employ a variant of the primal-dual approach incorporating multiple centrality correctors	Effectively diminishes the dimension of the coordination problem and the constraints count.	There is no comparative analysis provided to substantiate the method's efficiency when compared to alternative techniques.
ANN, AI [63,64,65,66]	Fast recursive discrete Fourier transform (FRDFT)	The FRDFT algorithm is employed to effectively track varying power system signals at their fundamental frequencies, coupled with Fuzzy logic decision making (FLDM) to derive optimal protection settings for diverse network topologies	It seamlessly coordinates with other numerical relays, offering computational efficiency	The challenging task of identifying all potential network topologies remains.

	ANN	Applied for forecasting the timing of relay operation mis-coordination	Can identify the optimal solution for medium-sized radial networks	Still results in instances of mis-coordination.
	Adaptive neuro- fuzzy	Suggested modification of OCR pick-up currents using instantaneous and current-voltage based inverse-time units	This development pertains to the time characteristic curve (TCC) relay	Its application remains constrained within radial system networks.
	Cascade Forward Neural Network (CFNN)	Utilizing a cascade neural network model, the comparison of neuron counts and learning rates is conducted during both the learning and testing phases	This is employed within the loop system network, where maximizing weight in the iterative process aims to attain an appropriate error value according to the pre-set objective	The presence of complications in DG fault current significantly impacts the reliability of the sampling rate.
	Levernberg–Marquardt ANN based	Application of a user-defined characteristic curve to the OCR	Offering a convenient alternative for curve selection compared to the conventional OCR, especially during the implementation phase	It does not address mis-coordination issues and lacks validation on the network system

2.1 Conventional Techniques

Before the advent of computer technology, relay settings in power systems were manually adjusted by network operators through conventional methods, which proved to be labour-intensive, inaccurate, time-consuming and unsafe. Conventional techniques for relay coordination have traditionally employed three main approaches [30]:

- a) The trial-and-error method: Involves a manual iterative process of adjusting relay settings until desired coordination is achieved. While simple, this approach has low convergence rates, required significant computational effort and time and may not be effective for large-scale and more complex networks [25, 26, 31].
- b) Curve fitting techniques: Relied on topological analysis and graphical and functional dependencies and involve mathematical modelling of the over-current relay (OCR) characteristics [32, 33]. These models are used to determine the appropriate TMS and relay operating time based on the specific characteristics of the system [27, 34]. This approach provides a more accurate coordination solution but can be more complex to implement.
- c) Graph theory approaches: It leverage network analysis to identify break-point relays (BPS) that plays a crucial role in initiating the coordination process, used to define and evaluate network loops and relay pairs [31]. This approach is highly accurate in coordination but could be most complex to implement for the intricate analysis involved [35]. Though it improved coordination in multiple distributed generation (DG) power networks, it fell short in optimally handling multiple coordination scenarios [36].

The choice of approach depends on the specific network characteristics and the requirements of the protection system. While the trial-and-error method is simple, it is not suitable for large networks. Graph theory approaches provide the highest accuracy in its category, but may require more sophisticated analysis [37, 38]. In response to these challenges, intelligent optimisation techniques emerged as a promising solution. These techniques eliminate the need for breakpoints and provide a more optimal TMS relay operating time and protective system coordination (PSC) [37].

2.2 Computational Techniques

To overcome the challenges posed by conventional methods, various computational and intelligent techniques were proposed as alternatives for optimal over-current relay (OCR) coordination [39]. These approaches encompass a range of optimisation strategies that leverage computational intelligence methods to achieve efficient coordination. By integrating protective devices with computational intelligence, these strategies enable the selection of more accurate strategy for protection of a given distribution network (DN) [40]. The citation percentage trends in recent years on OCR coordination research indicate a growing inclination towards hybrid techniques and mathematical-based optimisation, while the adoption of artificial intelligence techniques has been comparatively lower [41]. The preference for hybrid techniques stems from their advantageous features like robustness, fast convergence, and reduced search time for feasible solutions. These contribute to effective resolution of optimisation problems, leading to the optimal relay settings which result in efficient protection for the DN [42]. Figure 2 shows a typical application of over-current relays in feeder protection, integrated with intelligent control and monitoring within a distribution system [43].

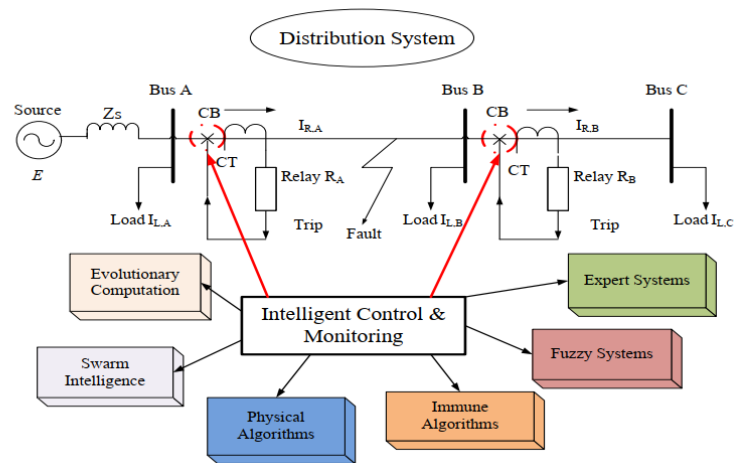


Figure 2. Integration of intelligent control and monitoring with OCRs.

2.2.1 The NIA-Heuristic Technique

This is an iterative approach that aims to identify high-quality solutions for relay coordination problems. In recent years, intelligent methods most of which were inspired by natural phenomena and animal behavior, known as nature-inspired algorithms (NIA), have emerged as powerful tools for addressing problems, demonstrated superior performance compared to traditional approaches and have been particularly applied to relay coordination. Notable among these are evolutionary programming, particle swarm optimisation (PSO), genetic algorithms (GA), firefly algorithms (FFA), artificial bee colony algorithms (ABCA), whale optimisation algorithms (WOA), teaching learning-based optimisation (TLBO) algorithms, electromagnetic field optimisation (EFO), biogeography-based optimisation (BBO) algorithms, gravitational search algorithms (GSA) and other techniques based on random search principles [44-46]. These methods are capable of generating feasible and near-optimal solutions by leveraging the principles of evolution, natural selection, and other observed behaviours. Although they do not guarantee finding the absolute best solution, they have a higher likelihood of discovering improved solutions [47].

The optimal coordination of overcurrent relays (OCRs) is a challenging problem in power system protection. To address this problem, researchers have explored various techniques, including mathematical optimisation methods and hybrid approaches that combine meta-heuristic techniques with mathematical programming [67, 68]. Mathematical optimisation methods, such as linear programming (LP) and nonlinear programming (NLP), have been utilised to solve the OCR coordination problem [69]. LP focuses on optimizing the TMS values to achieve selectivity between relays, while NLP simultaneously optimises both the TMS and pickup setting current values [23]. These methods offer convergence and near-optimal solutions but require significant computational effort.

2.2.2 Mathematical Techniques

Mathematical techniques in OCR coordination involve deriving numerical formulas based on mathematical formulations. These techniques aim to obtain optimal relay settings by formulating the coordination problem as a mathematical programming task [70]. Researchers have explored novel optimisation approaches to achieve accurate and reliable settings for all protection schemes, particularly for distributed generation in distribution networks [71].

Some studies have approached the relay coordination problem as a nonlinear programming problem and employed various optimisation techniques to solve it. However, these techniques often prove to be complex and time-consuming. In certain cases, the problem has been designed to be mixed-integer nonlinear programming (MINLP) and solved with specialized software like the general algebraic modeling system (GAMS) [72]. However, incorporating discrete protective system coordination (PSC) into the problem formulation introduces binary variables, increasing the complexity of coordination.

To address these challenges, linear programming (LP) methods like simplex, dual simplex, and simplex two-phase have been utilised in overcurrent relay coordination [73]. These techniques rely on initial predictions and may encounter difficulties in escaping local optima. In these LP-based approaches, the plug and play current and relay operating times are assumed to be linear mathematical functions with respect to the TMS [23]. Additionally, an M-method was suggested to determine the optimal TMS value for over-current relays, assuming a fixed plug and play current [24]. A comparative analysis has been conducted among the LP and M techniques, and dual-simplex process to evaluate their performance [74].

Mathematical techniques in OCR coordination offer potential solutions and involve formulating the problem as a mathematical programming task and applying optimisation techniques to determine optimal relay settings [75]. Considering challenges of complexity and computational time, further research to improve the effectiveness of these techniques and explore alternative mathematical approaches is needed [76, 77].

Linear programming (LP), nonlinear programming (NLP), mixed-integer programming (MIP), mixed-integer nonlinear programming (MINLP), and branch and bound are commonly utilised optimisation techniques in the relay coordination problem [78]. However, these methods suffer from limitations such as high dimensionality and low computational efficiency. In a study, the mixed-integer programming problem (MIP) was formulated for coordinating overcurrent relays. To overcome the challenge of local optima, updating global best (Gbest) and position best (Pbest) values for each iteration has been proposed

[79]. Additionally, an on-line risk evaluation approach has been implemented to identify vulnerable areas and estimate probabilities of relay mis-coordination using the event tree approach. Another study employed linear programming (LP) to optimise the TMS while pre-defining the pickup setting current [23]. Sequential quadratic programming (SQP) was utilised to find the solution for OCR coordination based on fault location at the near end, ensuring optimality. Furthermore, to prevent blinding trips, additional constraints of near-end selectivity and remote-end selectivity were applied, with a two-stage approach designed to address this challenge. While this method avoids constraint violation by relaxing the constraints, it may consume more time due to network complexity [24].

Mathematical approaches are effective in dealing with relay coordination in simple transmission networks. However, when it comes to interconnected power networks with a large number of relay coordination pairs, the complexity of the coordination constraint matrix increases, and the mathematical approach may get trapped in local minima within the search space. To overcome this limitation, researchers have turned to nature-inspired algorithms (NIAs) and hybrid approaches to achieve the global optimum solution for coordination problems [80].

2.2.3 Hybrid Approaches

These combine meta-heuristic techniques with mathematical programming to improve the efficiency and effectiveness of the optimisation process. For instance, the hybrid gravitational search algorithm and sequential quadratic programming (GSA-SQP) have been employed for OCR coordination [81]. Additionally, techniques like genetic algorithms (GAs), differential evolution (DE), and biogeography optimisation have been used to obtain optimal OCRs coordination [82]. Despite many proposed hybrid approaches, there is still room for exploring new combinations of meta-heuristic techniques and mathematical programming. By further investigating these hybrid approaches, researchers can potentially discover more precise and computationally efficient solutions for optimal OCR coordination [83].

The optimal coordination of OCRs is a complex problem that can be addressed through mathematical optimisation methods and hybrid approaches. These techniques offer the potential to improve the efficiency and accuracy of OCR coordination, contributing to the reliability and effectiveness of power system protection. Future researches were mused to focus on exploring new combinations of techniques and developing innovative approaches to tackle challenges in OCR coordination [84].

2.2.4 The NIA-Heuristic and Hybrid Approach

These approach combines meta-heuristic techniques, like deterministic and multipoint search optimisation, to find optimal global solutions for relay coordination within a short computational time [85]. In the early 2000s, researchers introduced evolutionary programming (EP) to the protection scheme, but they faced challenges related to relay mis-coordination and variable selection for TMS [86]. To address these challenges, genetic algorithms (GA) were employed to identify the relay operating time, both for linear and nonlinear objective functions. Particle swarm optimisation (PSO) was also found to be effective in resolving mis-coordination issues compared to EP and GA algorithms, for both continuous and discrete TMS and pickup setting current settings [87]. Modified PSO algorithms were proposed to optimise relay settings using the mixed-integer nonlinear programming (MINLP) formulation based on DE [62].

To enhance the effectiveness and convergence of the NIA-heuristic technique, researchers have developed hybrid approaches that combine classical and NIA optimisation methods by dividing the optimisation problem into sub-problems that are individually solved using specific algorithm. For these hybrid algorithms, each is solved using a specific algorithm. They integrated mathematical and NIA-heuristic methods or employ multiple NIA-heuristic techniques to effectively address highly constrained OCR problems [24]. Typically, optimal OCR coordination problems are formulated as linear programming problems (LPP) with predetermined current pick-up settings [88]. The operating times of the relays are represented as linear function of its TMS. However, these approaches often exhibit slow convergence, increased implementation complexity, and high computation time requirements [26].

In the field of OCR coordination, researchers have explored various techniques to optimise relay settings. In [70] application of numerical relays and proposal of hybrid approach, BBO/DE, considering numerical and electromechanical OCR relays were done. However, the use of static OCR presents challenges due to the need for a confined, feasible search space with less accurate time. An improved hybrid BBO/DE algorithm was introduced to forestall mis-coordination and constraints of relay violations [89]. Another promising solution was presented in [71] by combining whale optimisation algorithm (WOA) and search algorithms (SA). Convex optimisation and problem relaxation techniques have also been explored to reduce relay operating times in complex networks. Nevertheless, mis-coordination remains a concern with these techniques [90].

2.2.5 Artificial Neural Networks (ANN) and Artificial Intelligence (AI)

NIA-heuristic and hybrid approaches have shown potential in addressing relay coordination issues in large networks and achieving optimal solutions [84]. However, they are limited to fixed network topologies and struggle to handle extensive load profile data. To overcome these limitations, researchers have turned to AI techniques [91]. The use of ANN to forecast relay mis-coordination was proposed in [23]. A hybrid GA-ANN approach to determine optimal operating times for protective relays was developed in [84]. However, the elimination of mis-coordination among relay pairs was not significantly improved.

A major challenge in these solutions lies in storing and utilizing a large amount of data related to protection settings. As networks expand and more DGs are added, collecting extensive data becomes necessary to account for additional conditions. Furthermore, interpreting the proposed structure becomes crucial when the current micro-grid condition does not match any stored protection settings. To address these challenges, a flexible approach is required. Fuzzy logic integrating with ANFIS structure into the relay model for optimal coordination was proposed [92]. This approach performs well under various conditions, with minimised topological changes. However, it focuses on a single type of relay, limiting its applicability [27].

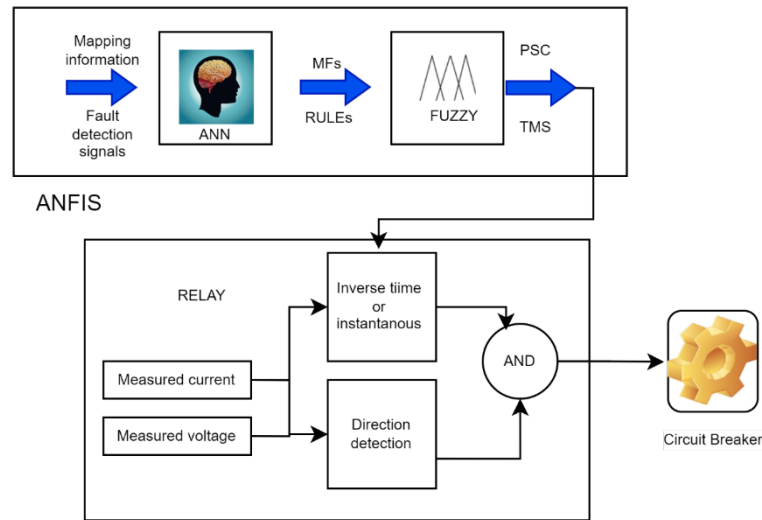


Figure 3. An ANFIS-based adaptive relaying approach [94].

Researchers have made progress in optimising OCR coordination through techniques such as numerical analysis, heuristic algorithms, mathematical programming, and AI. Each has its strengths and limitations, and more work is needed to overcome challenges and develop more flexible and efficient methods for OCR coordination [84]. The utilization of artificial intelligence techniques, including artificial neural networks (ANN) and AI, shows promise in addressing relay coordination challenges [95]. However, there are still obstacles to overcome, such as data storage and utilization, as well as the need to consider different network conditions. Flexible approaches, like the adaptive neuro-fuzzy interface system (ANFIS), offer potential solutions by integrating fuzzy logic and ANN into relay models to optimise performance in diverse network scenarios [96]. In Figure 3, the ANFIS-based adaptive relaying approach was proposed. These approaches aim to improve the effectiveness and adaptability of relay coordination, contributing to the development of more efficient and reliable power systems.

3. CONCLUSION

This paper examines the coordination of optimal over-current relays (OCRs) by identifying existing techniques and highlighting gaps in current research. It discussed the strengths and limitations of these techniques. Ongoing research in this field is driven by the emerging challenges in power system networks, like network expansion, increased penetration of DGs, and integration of smart grid technologies. A comprehensive review of current state-of-the-art techniques for optimal over-current relay (OCR) coordination in power system protection is hereby presented. Recommendations for future studies to further enhance OCR coordination and improve grid operation, security, and reliability are also given. Continuous research efforts are vital to develop efficient protection schemes that can effectively address the emerging challenges of the future.

Future research in the field of optimal OCR coordination is essential to improve the efficiency and reliability of OCR coordination, particularly in the context of evolving power systems with increased complexity and the integration of distributed generation. These should focus on the following:

- 1) Overcoming or minimising the impact of constraints on relay coordination, which may involve exploring strategies that increase the feasible solution space and reduce the complexity of the coordination problem, while still ensuring coordination constraints are satisfied for different network topologies.
- 2) Inclusion of new user-defined relay characteristics curves can lead to more optimal solutions in relay coordination.
- 3) Combination of ANN and fuzzy logic should be explored for numerical relay coordination, particularly in dealing with uncertain and ill-defined systems, especially in the context of integrating distributed generation (IDG). Developing specific neural network models dedicated to modelling OCRs can improve the accuracy of outcomes. Incorporating specialized microprocessors to store protection algorithms with various settings can address the memory requirements of mathematical-based models.
- 4) Utilisation of multiple meta-heuristic methods, incorporating variations in coefficients or combining multiple steps of standard techniques, should be considered.
- 5) Establishing appropriate coefficient ranges can help mitigate risks of divergence, particularly in large networks with high distributed generation penetration and dynamic load retransmission.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare no potential conflicts of interest with respect to the research and publication of this article.

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